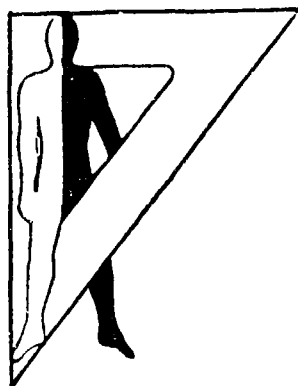


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THE ACOUSTIC STARTLE RESPONSE AND DISRUPTION OF
AIMING: II. MODULATION BY FOREWARNING AND PRELIMINARY STIMULI

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The Acoustic Startle Response and Disruption of Aiming: II. Modulation by Forewarning and Preliminary Stimuli

JOHN A. FOSS, *Argus Research Laboratories, Horsham, Pennsylvania*, JAMES R. ISON,¹ *University of Rochester, Rochester, New York*, and JAMES P. TORRE, JR., and SAMUEL WANSACK, *Aberdeen Proving Ground, Maryland*

Four experiments examined the disruption of rifle aim by intense noise bursts. In Experiment 1 a trigger pull was followed occasionally by a noise burst. Aiming was disrupted for 1-2 s, an effect that habituated within days and recovered between days. Expected stimuli were less disruptive than were unexpected stimuli. Experiment 2 demonstrated that weak auditory prestimuli 100 ms before unexpected intense sounds also reduced noise-produced errors. Experiment 3 showed that the intratympanic reflex had not played a protective role in this effect. Experiment 4 showed that a weak tactile prestimulus increased both a muscular measure of the acoustic startle reaction and the perturbing effect of the noise burst on motor performance. In general, conditions that affect the amplitude of the acoustic startle reflex similarly influence the disruptive effect of a noise burst on motor performance, but the two measures are not correlated in the detail necessary to suggest a causative relationship.

INTRODUCTION

Sudden and intense acoustic stimuli elicit startle reflexes (Landis and Hunt, 1939) and interrupt ongoing behavior and cognitive activities (Culbert, 1960; Lukas and Kryter, 1968; May and Rice, 1969; Plutchek, 1959; Thackray and Touchstone, 1970, 1983; Vlassek, 1969; Woodhead, 1958, 1959). The intent of the present work and the previous study in this series (Foss, Ison, Torre, and Wansack, 1989, this issue) was to determine whether conditions that affect the reflexive response

to intense noise bursts also affect their disruption of human perceptual-motor performance.

The eye-blink component of the startle reflex to noise bursts or to cutaneous stimuli on the forehead is inhibited when subjects either present the stimuli to themselves or are warned when the stimulus is about to be presented (Cohen, Cranney, and Hoffman, 1983; Sanes, Foss, and Ison, 1982). These findings are consistent with the general understanding that surprise is an important feature of the effective startle stimulus. Similarly, the startle reflex is attenuated by brief, irrelevant stimuli in a variety of modalities—auditory, visual, or tactile—which occur just be-

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fore the eliciting stimulus (for reviews see Hoffman and Ison, 1980; Ison and Hoffman, 1983). This effect seems to be accomplished primarily by brainstem mechanisms that inhibit motor output (Leitner, Powers, Stitt, and Hoffman, 1981) and perhaps involves sensory and afferent inhibition as well (Cohen, Hoffman, and Stitt, 1988; Wu, 1987).

In the experiments reported in this article we considered how forewarning and preliminary stimuli might moderate the disruption of a perceptual motor response—aiming at a fixed target—which results from the occurrence of brief but intense noise bursts.

EXPERIMENT 1

Method

Subjects. The research participants (male, $N = 22$) were recruited from introductory psychology classes or through ads posted on campus. The subjects received hearing tests each day they participated in the experiment before and after their exposure to the stimulus conditions. Subject selection procedures and other details are presented in Foss et al. (1989).

Stimulus generation. The apparatus necessary for delivering the stimuli is described in detail in Foss et al. (1989). Briefly, white noise was filtered to produce an octave band of noise around 250 Hz; shaped by an electronic switch and a zero-crossing gate for a duration of 50 ms with 0.5 ms rise and decay time; and amplified to a peak pressure of 130 dB SPL. The stimuli were presented over headphones.

Aiming performance. The task is more fully described in Foss et al. (1989). Subjects stood with one elbow resting on a sandbag, aiming a rifle at a target. A solid-state video camera mounted on the rifle presented an image of the target to a tracking system that computed the horizontal and vertical deviations from the initial "on-target" position. A piece

of white Mylar attached to the sear of the uncocked rifle reflected light back to an infrared emitter-detector when the trigger was squeezed. The output of the sensor reset a flip-flop that had been set by the experimenter and thus controlled the time of delivery of the eliciting stimulus.

Procedure. Subjects performed two series of 30 aiming trials, the second series following the first by a rest period of 15 min. The intense noise burst occurred on eight occasions in an irregular sequence within each of the two series, on average 2 min apart. On four of these trials the subject was informed at the start of the trial that the noise burst would occur 0.5 s after the trigger pull. On the other four trials the loud noise occurred without warning 0.5, 1.0, or 1.5 s after the trigger pull. Four other trials in each sequence were designated as blank trials and provided the control data for aiming accuracy in the absence of the noise burst. For half the subjects the first noise burst was expected and the second unexpected; for the other half the order was reversed.

Ten of the 22 subjects participated two additional test days, one on the succeeding day and then seven days later. The basic pattern on all days was the same, although the exact sequence of trials was varied.

Analysis. The mean of the deviations from target in the 5.0-s period before the stimulus was used as the baseline and was subtracted from each value in the prestimulus and post-stimulus periods. The magnitude of the vector sum of the deviations in the azimuth and elevation planes was calculated at each time point and the means computed for 500-ms intervals from 1.5 s before the stimulus to 5.0 s after the stimulus. When reactions to the noise were so extreme that the tracking device was unable to follow the target, the missing data were replaced by the maximal values from adjacent segments. The data were analyzed using the 2V program of the

BMDP statistical software (Dixon, 1983), the dependent variable being the maximum of the absolute mean deviations. Given that temporal factors often produce violations of the symmetry assumptions of repeated-measures designs, the degrees of freedom for within-subjects factors were reduced using the Huynh-Feldt adjustment.

Results and Discussion

Data from the warned and unwarned trials on the first day are presented in Figure 1. It is clear that the intense sound burst momentarily disrupted aiming, that the size of the performance disruption declined over trials, and, of particular importance, that the performance disruption was smaller when the subject was informed that the noise would follow his pulling the trigger. As in the previous report (Toss et al., 1989), a subset of subjects became confused when they heard

the noise, and they immediately put the rifle down or forgot to continue aiming after the noise. This happened on one trial each for seven subjects, five on trials when the noise was not expected and two when it was expected.

Analyses of variance of the maximum perturbation in the first four 500-ms intervals provided a main effect of warning, $F(1,20) = 25.05, p < 0.01$; a main effect for the first period as opposed to the second period of the session, showing that habituation had occurred, $F(1,20) = 7.15, p < 0.05$; and an interaction of period and warning that resulted because the warning effect was most pronounced in the first half of the day, when the perturbations on unwarned trials were more extreme, $F(3,60) = 4.55, p < 0.01$. Similarly, an interaction of trials and period resulted, $F(3,60) = 4.55, p < 0.01$, because responses declined over trials more rapidly in the first

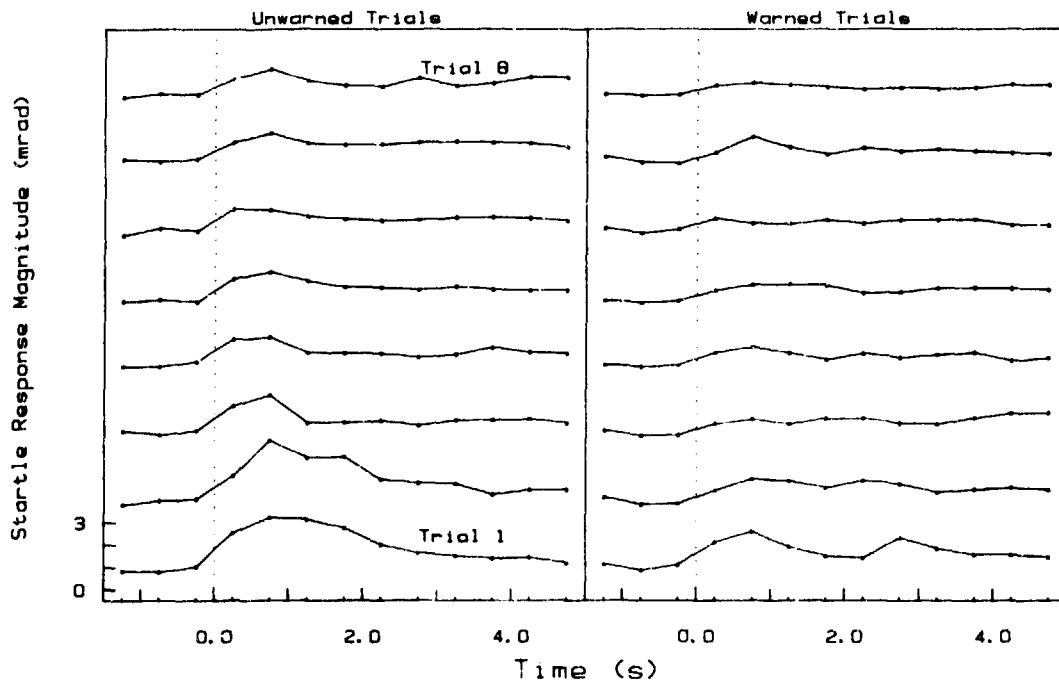


Figure 1. Mean absolute deviations from target before and after noise burst on warned and unwarned startle trials.

period of the session. Although there was a decrement in the effect of the noise within the day, the noise was still a significant factor on the last trial, $t(21) = 2.88, p < 0.01$.

The protective benefit of anticipation was present in the first pair of trials. The first unexpected noise gave rise to a mean response perturbation of 4.30 mrad, whereas the first expected noise was followed by an error of 3.04 mrad, $t(21) = 13.94, p < 0.01$. Overall the average error produced by unexpected stimuli was 3.13 mrad and by expected stimuli, 2.37 mrad, compared with an average maximum error on blank trials of 1.86 mrad. If it is assumed that the error induced by the noise simply summated with the normal jitter in aim, then the effect of the unexpected noise by itself was 1.27 mrad ($3.13 - 1.86$) and the effect of the expected noise was 0.51 mrad ($2.37 - 1.86$). It may be concluded that warning the subject that the noise was impending moderated its disturbing effect by about 60%.

Examination of the mean absolute deviations in the three 500-ms periods just before the noise burst (Figure 1) reveals no indication that the anticipation of a noise burst affected aiming performance either immediately prior to the trigger pull or immediately before the anticipated noise. In the blank condition the three periods had mean errors of 1.18 mrad, 0.93 mrad, and 1.02 mrad and for the warned condition the means were 1.11 mrad, 0.92 mrad, and 1.00 mrad, respectively. The two sets of data are virtually identical. The middle period showed the greatest accuracy under both conditions, an effect seen for all 22 subjects. It is interesting that this is the period that ended in a trigger pull: it is possible that the subjects chose to pull the trigger in recognition of their momentary greater accuracy, or otherwise that their intent to pull the trigger at that particular time led to their more accurate performance.

The data for the 10 subjects who continued

in the experiment for two more days are presented in Figure 2. It is clear that the protective effect of warning persisted over the three-day period, that the disruptive influence of the stimulus habituated over trials within each day, and the habituation partially dissipated between days. Analyses of variance of the maximum mean disruption showed that warning the subject had a reliable protective effect, $F(1,9) = 29.70, p < 0.01$, and that errors declined over days, $F(2,18) = 13.48, p < 0.01$. There was no difference in the effectiveness of the warning instructions across days: the mean differences on each day between the warned and unwarned conditions were 0.87 mrad, 0.83 mrad, and 0.90 mrad, respectively. However, habituation to the noise burst was very apparent in both the second and the third day of training. Compared with the blank trials, there was no significant effect of the noise on the last trial of either of these two days (1.89 mrad vs. 1.84 mrad on Test Day 2, and 1.55 mrad vs. 1.37 mrad on Test Day 3, $t_s < 1$). Significant recovery occurred from the last trial of Test Day 2 to the first trial of Test Day 3, $t(9) = 2.53, p < 0.05$. The decision to continue running trials with these 10 subjects was made to determine whether a perturbation in aim in anticipation of the noise might develop with more training. Examination of Figure 2 reveals that it did not: there was no evidence for an additional error response immediately prior to the expected noise.

On unwarned trials the noise burst came at a variable interval after the trigger pull (500, 1500, or 2500 ms) in order to minimize the extent to which the subject might come to anticipate the stimulus in this condition. In the warned condition the interval was always 500 ms. We recognized that this procedural difference could provide a possible source of confounding between the conditions, but it was considered important to reduce the consistency of the unwarned condition. The in-

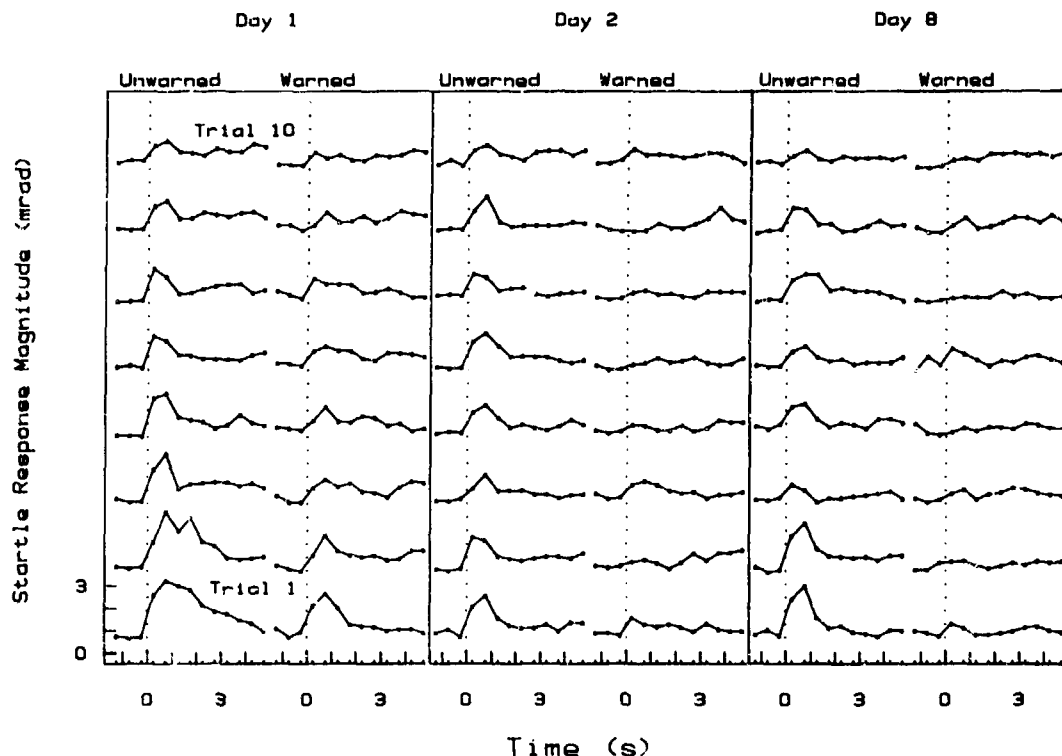


Figure 2. Mean absolute deviations from target before and after noise burst on warned and unwarned trials over three days.

fluence of this potential confound could be assessed by comparing error responses to the expected noise at 500 ms with those produced by the unexpected noise at this same interval. Records of the particular interval between trigger pull and the noise burst were available only for the last eight subjects on the last day of training. For these subjects the error response to the expected noise was 1.44 mrad, whereas response to the unexpected noise with the same 500-ms interval was 2.04 mrad. This difference was reliable, $t(7) = 3.07$, $p < 0.05$, and revealed that the subjects' aim was disrupted less when they expected the noise, in addition to any influence that the trigger pull alone might have had at a 500-ms interval.

In this experiment warning the subjects

that their responses would generate an intense noise burst partially protected the motor response and did not evoke any anticipatory disturbance in aiming. Woodhead (1958) had reported that a visual cue warning of an impending noise did not attenuate its disruptive effect on a complex cognitive task and may have further degraded performance in some subjects. The noise in her study was less intense but of longer duration than that in ours and the task considerably different. Further, a quarter of her subjects described the warning cue as being itself a distracting stimulus. Obviously, the beneficial effects of warning could be considerably compromised if the warning itself disrupted performance.

The effects of stimulus repetition in this experiment largely duplicated those described

in the prior report (Foss et al., 1989) showing a decline in the size of the error with repeated experience and a recovery following a rest. However, habituation was more pronounced in the present case. This may have resulted because of one or two procedural differences. A most obvious difference is that the present experiment included an additional six trials in each session. More within-days habituation might have occurred simply because of this greater number of trials. However, the major habituation decrement appears early within the first set of trials, where the difference in the total numbers of trials each day could not yet be effective. Perhaps of greater importance is the difference between the two experiments in the certainty about when the stimulus could and could not occur: in the present experiment the noise burst always occurred following a trigger pull, whereas in the former experiment it was unpredictable. The appearance of greater habituation here suggests that having at least partial control over the noise burst or some information about its impending occurrence may promote faster adaptation.

EXPERIMENT 2

The ability of weak preliminary stimuli to moderate the somatic reflexes and psychophysiological consequences of intense stimuli has been studied in the laboratory for about a century (see Ison and Hoffman, 1983). No prior experiment has examined the possibility that preliminary stimuli might also reduce the disruptive effect of intense stimuli on perceptual-motor behavior, though Hoffman and Fleshler (1963) suggested this possibility as a way to improve performance in noisy environments.

Method

Subjects. Subjects (all male, $N = 20$) were taken from the same population used in the prior experiments and were treated similarly

except for the details of the experimental procedures.

Stimulus generation and performance. The eliciting stimulus was that used in the prior experiment. The preliminary stimulus was a 1000-Hz tone burst with a total duration of 25 ms which included 5-ms rise and decay times. The interval between the onset of the preliminary and the eliciting stimulus was 100 ms, and the peak pressure for the preliminary stimulus was 80 dB. The aiming task was the same as that used previously.

Procedure. Subjects received two series of 30 aiming trials, the second series following the first by a rest period of 15 min. On eight occasions, on average every four trials, the 130-dB noise burst occurred between 5 and 10 s into the trial. On four of those trials the intense noise was preceded by the 80-dB tone burst. Four other trials in each series were designated as blank trials and provided the control data for aiming accuracy in the absence of the noise burst. In half the subjects the intense noise was presented alone on the first stimulus trial, and for the other half the tone-noise combination occurred first. The data were analyzed using the same methods used earlier.

Results and Discussion

On 30 trials the noise disrupted aiming so much that the tracker could not follow the perturbation: on 26 the noise occurred by itself and on 4 the noise was preceded by the weak tone. Ten subjects gave one or more of these extreme responses, and for nine of these subjects the responses were more common on noise-alone trials compared with tone-plus noise trials. This difference was significant (from the binomial, $p < 0.05$). One subject became confused on a noise-alone trial and put the rifle down immediately after hearing the stimulus.

Figure 3 gives the mean absolute error in aiming on each of the eight noise-alone trials

and the eight trials in which the tone preceded the noise for three 500-ms periods before and ten periods after the noise burst. Table 1 presents the averages of the individual maxima of the mean-error scores on trials when the intense noise burst was given alone, on trials when the noise was preceded by the weak tone pulse, and on baseline control trials. When the intense noise burst was presented by itself, it increased the size of the maximum aiming error on each trial by about 50%—that is, a gain of 0.99 mrad from 2.07 mrad in the control condition to 3.06 mrad in the noise condition. In contrast, when the noise burst was preceded by the weak tone, the mean error was 2.41 mrad, just 0.34 over the control value. It is noteworthy that the weak tone reduced the error produced by the intense noise burst by approximately two thirds—that is, from 0.99 mrad to 0.34 mrad.

It is clear from Table 1 that the amplitude of the deviation from the target declined over the series of eight trials within each stimulus condition and also that the preliminary tone pulse protected performance from the full effect of the intense noise throughout the entire series of trials. Analysis of these data showed that the beneficial result of the preliminary stimulus in reducing performance error was reliable, $F(1,19) = 13.50, p < 0.01$. There was no systematic change in aiming performance across the blank control trials, $F < 1$. In contrast, errors induced by the noise stimulus were reduced in the second half of the experiment compared with the first half, $F(1,19) = 5.02, p < 0.05$, and declined over trials in each half of the experiment, $F(3,57) = 4.33, p < 0.01$, primarily in a linear manner $F(1,19) = 6.56, p < 0.02$. Combining these two effects resulted in a reduction in error of 0.93 mrad between the first and the last trials of the

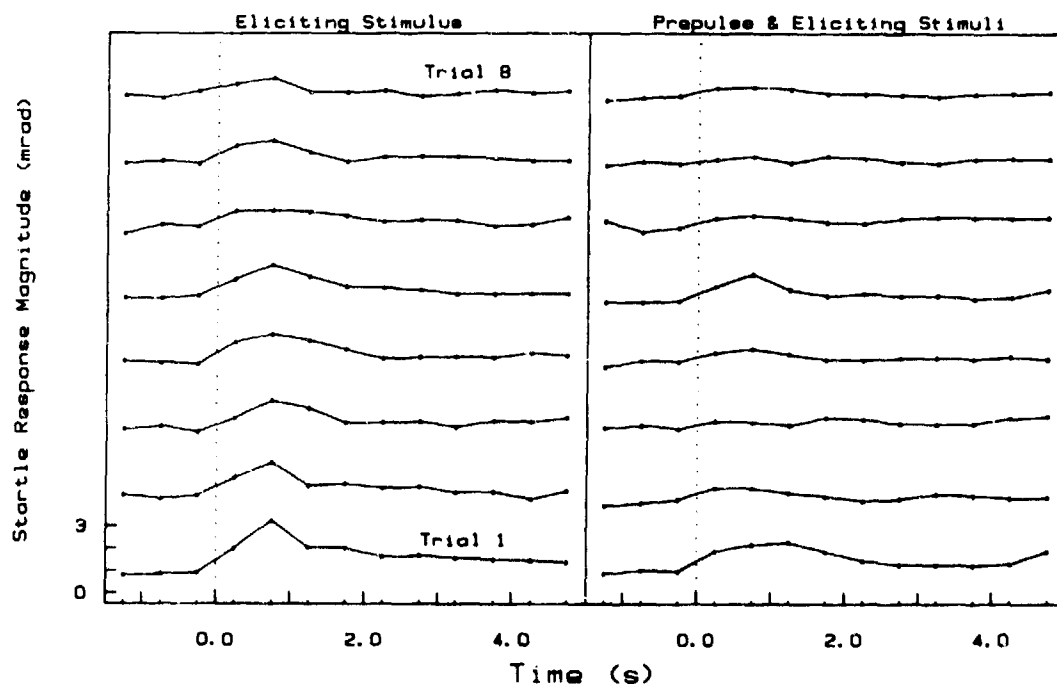


Figure 3. Mean absolute deviations from target before and after noise burst on trials preceded by an acoustic preliminary stimulus and control trials.

TABLE 1

Averages of the Individual Maximum Mean Errors (mrad)

Trial	Condition		
	Control	Startle	Prepulse & Startle
1	1.85	3.40	3.08
2	1.96	3.42	2.29
3	1.94	2.95	2.41
4	2.77	3.40	2.43
5	2.18	3.11	2.55
6	2.17	2.87	2.30
7	2.06	2.86	2.07
8	1.65	2.47	2.16

day. There was no recovery in the amplitude of the response disruption induced by the first noise following the 15-min rest period compared with the effect of the last noise prior to the rest.

The data obtained on noise-alone trials confirm the earlier data in showing that these intense stimuli disrupt aiming performance and that their effectiveness declines with stimulus repetition. The experiment demonstrated additionally that weak preliminary stimuli can reduce the disruptive influence of acoustic startle stimuli on motor performance. Previous experiments have shown that the effectiveness of the preliminary stimulus in inhibiting reflex activity is determined in part by its intensity and in part by the time interval by which it leads the eliciting stimulus (see Hoffman and Ison, 1980). It is important to note that the interval between the two stimuli in this experiment was 100 ms, which is in the optimal range for reflex inhibition to occur, and that the initial stimulus was effective without explicit warning from the beginning of the experiment. That the 100-ms interval is considerably less than a voluntary reaction time and that the tone was effective on its first occurrence both argue that the subjects did not have to learn

some defensive response that would moderate the disturbing effect of the noise burst.

EXPERIMENT 3

Although it is unlikely that the preliminary tone evoked a learned defensive response to reduce the disruptive effects of the intense noise burst, it may have activated the intratympanic reflex. This reflex of the tensor tympani and stapedius muscles changes the impedance of the middle ear and thus reduces the functional intensity of loud noises of low and middle frequencies (see, for example, Morgan and Dirks, 1975; Sesterhenn and Breuninger, 1978). It has been shown to protect against the threshold shifts and cochlear damage attendant on exposure to intense impulsive noises when it is elicited by moderate stimuli presented just before the intense burst, in a procedure similar to that used in the prior experiment (Fletcher and Riopelle, 1960; Hilding, 1960).

Ison, Reiter, and Warren (1979) had shown that a weak tone inhibited the eye-blink to a more intense tone burst without eliciting the intratympanic reflex. However, the hypothesis that the intratympanic reflex was involved in the present demonstration is raised again because the earlier experiment had used a weaker tone (70 dB vs. 80 dB in the present report) and had not measured performance disruptions, which may not follow quite the same rules as reflex expression. Data provided by Djupesland (1975, pp. 98–99) also suggest that the threshold for the intratympanic reflex might approach 100 dB for brief stimuli, arguing further against the hypothesis that the intratympanic reflex is involved in these experiments. However, the intratympanic reflex traditionally is held responsible for protecting the organism from intense noise bursts, and thus its potential contribution to the present effect should be assessed.

For these reasons the present experiment measured the impedance of the middle ear to determine whether the intratympanic reflex was elicited by the 80-dB preliminary stimulus during perceptual motor performance. In addition, reflex activity in the eyelid muscles was measured to provide further information on the relationship between the disruption of performance induced by the intense noise burst and its elicitation of the startle reflex.

Method

Subjects. Five male subjects, volunteers from laboratories in the Department of Psychology, participated in this experiment. In addition to the preliminary hearing test, a tympanogram using a Madsen Model ZO70 electroacoustic impedance bridge was taken prior to beginning the experiment.

Apparatus. Aiming performance, impedance changes in the middle ear (using the Madsen bridge), and electromyographic activity of the eyelid were measured in this experiment. The aiming task was as described in the previous experiment. In Experiment 3 only the deviations in the azimuth plane were recorded because the second channel of the apparatus was used for the impedance measure rather than deviation in aiming.

The impedance changes in the ear opposite the eye used for sighting provided a measure of the intratympanic reflex. The voltage output from the bridge was recorded on the digital oscilloscope, and the traces were later examined for responses exceeding the baseline noise. The latency to reflex onset, the latency to peak, and peak voltage were measured first between the preliminary stimulus and the eliciting stimulus and then for 500 ms after the eliciting stimulus.

The response of an eyelid muscle was included as a measure of the primary startle reaction. Recording electrodes with adhesive collars were fixed over the inferior portion of

the orbicularis oculi muscle on the side used for sighting; one electrode was placed at the lateral canthus and the other in a medial position. The reference electrode was placed on the temple along the zygomatic arch. The electrode signals were conditioned by an FET preamplifier, amplified, rectified, and fed into an analog integrator that summed the response during the period from 30 to 90 ms after onset of the stimulus.

Procedure. The pattern of trials in this experiment was the same as that used in Experiment 1. However, the exact stimulus conditions of the previous experiment could not be duplicated because the bridge used one ear for its impedance probe and therefore only monaural noise bursts could be employed. (The earlier experiments had all presented binaural stimuli.) To offset this difference and to equate monaural intensity to the combined binaural intensity of the sounds, both the preliminary stimulus and the eliciting stimulus were increased by 6 dB. Therefore in this experiment the peak intensity of the preliminary tone was 86 dB and the startle noise burst was 136 dB.

Results and Discussion

When the noise burst was preceded by the acoustic preliminary stimulus, four of the five subjects showed reliable inhibition of the eye-blink reflex with values ranging from 51% to 84%, $2.75 < t(7) < 4.64$, $p < 0.05$. The anomalous subject had an excessive squint during aiming and thus showed considerable background EMG activity during the trials, which made blink recording problematic. At the end of the combined aiming and eye-blink experiment this subject was given an additional series of noise-alone and tone-plus-noise trials under rest conditions, and the normal inhibitory effect of the prepulse appeared and was significant, $p < 0.05$. The same four subjects for whom the preliminary

stimulus inhibited the eye-blink reflex also showed smaller errors in aiming when the tone preceded the noise burst. Improvement in aiming ranged from 19% to 75% and was reliable in the case of one subject, $t(7) = 5.47$, $p < 0.01$. Although the effect of the preliminary tone burst was the same on both reflex expression and performance disruption, correlations performed across trials within subjects showed no correlation between these two consequences of the intense noise bursts (mean $r = 0.06$).

Our primary purpose in this experiment was to test the hypothesis that the intratympanic reflex mediated the effect of the preliminary stimulus, the resulting decrement in effective stimulus intensity protecting aiming performance against the disruptive effect of the noise burst and reducing startle reflex expression. In order to provide this protective benefit, the reflex would have had to be elicited by the preliminary stimulus and therefore be present at the time of the noise burst. The data contradicted this hypothesis: on the 40 trials in which the tone pulse preceded the intense sound burst (eight trials with each of the five subjects), the preliminary stimulus never induced an anticipatory change in the impedance of the middle ear.

As anticipated from Djupesland (1975), the preliminary tone burst (86 dB at a 20-ms duration) was below the threshold of elicitation for the reflex. But as was also expected, the 136-dB noise burst exceeded the threshold intensity for the intratympanic reflex and induced a change in the impedance of the middle ear on every trial. It is interesting that the initial tone burst, itself below threshold for reflex elicitation, appeared to facilitate the intratympanic reflex in that the latency to its peak amplitude was reduced by a small but consistent amount, from 240 ms to 225 ms, $F(1,4) = 14.11$, $p < 0.05$. This facilitative effect on reflex recruitment seems to have no practical significance in the present setting,

however, because the tone did not alter the peak amplitude of the response or its onset latency.

EXPERIMENT 4

Prior work has shown that weak tactile stimuli inhibit a long loop reflex elicited by more intense tactile stimuli (Ison, Foss, Falcone, Sakovits, Adelson, and Burton, 1986). In addition, Blumenthal and Gescheider (1987) have reported that tactile stimuli similarly inhibit the acoustic startle reflex. In this respect tactile prestimuli are the equivalent of acoustic prestimuli, and these data, as well as others showing that visual stimuli also inhibit the startle reflexes (Reiter and Ison, 1977; Sanes, 1984), attest to the multimodal control of the mechanisms that moderate reflex behavior. The purpose of Experiment 4 was to discover whether the effect of the tone prestimulus in reducing the disruption of perceptual motor performance by startle-eliciting stimuli, demonstrated in the previous experiment, would be shared by a preliminary cutaneous stimulus. The empirical rationale for the study was to continue to extend the findings concerning startle reflex expression into the domain of perceptual-motor performance.

A second justification for this experiment was to investigate further the physical basis of performance disruption by intense noise bursts. Measures of the eye-blink component of the acoustic startle reflex had determined that neither trial-to-trial differences in the amplitude of the performance disruption within subjects nor between-subjects differences in this measure were related to differences in the blink reflex (Experiment 3 in this report, and Foss et al., 1989). This finding suggests that motor disruption is not produced mechanically as a result of startle reflex expression, but it is possible that eye-blink reactions are not representative of some other components of the startle reflex.

It may be that reflex activity in the arms or shoulders would be correlated with the degree of performance disruption because control over these muscles is critical to the motor task. Activity in the trapezius muscle was therefore measured in this experiment because it was thought that startle activity of this muscle, in contrast to the eye blink, might be contributing to aiming disruption.

Method

Subjects. The 20 male subjects were recruited as described in Experiment 1 and treated similarly.

Apparatus. The preliminary stimulus in this experiment was a weak electrical pulse delivered to each subject's face following the procedure used by Ison et al. (1986). A Grass Model SD5 stimulator produced a 5-ms stimulus that went to a Grass Model CCU1A constant current unit. The stimulus was delivered to the subject through two surface electrodes attached by adhesive collars to an area of the cheek at the side of the lower lip.

The dependent measures were aiming performance and EMG activity in the trapezius muscle. The aiming task was the same as before, and the data were handled in the same manner. Trapezius muscle activity provided another measure of an element of the primary startle reaction. Two surface electrodes were placed along the trapezius muscle at the base of the neck on the side opposite the eye used for aiming; the reference electrode was placed behind the ear over the mastoid process. Activity was integrated for the period between 50 and 150 ms after the onset of the eliciting stimulus. The differences between these values and those for the eyelid muscle represent the longer latency and more variable duration of responses from the trapezius.

Procedure. The pattern of control and preliminary stimulus trials was exactly that used in the first experiment. Two intensities

of the shock were used because we were uncertain about the effective level for this stimulus. One group of 10 subjects was studied with the level 2.0 times the cutaneous threshold; the other 10 subjects received preliminary stimuli 3.5 times the threshold. These values were chosen as approximating a minimal intensity that would be detected on every trial and also approximating a maximal intensity that would not itself disrupt performance (though 6 of the 10 subjects blinked from the higher-intensity shock on its first presentation). Each subject's threshold was determined by averaging the values obtained from two ascending and descending series using the method of limits. Neither stimulus was considered painful.

Results and Discussion

The aiming data are presented in Figure 4 and the data on trapezius EMG in Figure 5. The two prestimuli are combined in these figures, as analyses showed that the differences between groups (which approximated only 10% overall in favor of the greater intensity) were not significant. Performance disruption induced by the noise burst declined over trials, as did amplitude of elicited activity in the trapezius muscle, both measures demonstrating that subjects adapted to the noise. Contrary to expectation, the preliminary cutaneous stimulus enhanced the effect of the noise burst; this effect was seen in both performance errors and reflex reactions. This effect seems to indicate a fundamental difference between auditory and cutaneous prestimuli that has not been seen in previous work.

Analysis of variance of these data included both measures following a translation to standard scores in order to eliminate differences in units of measurement. One set of significant effects to emerge from this analysis resulted from habituation to the noise bursts. Both measures were greater in the first pe-

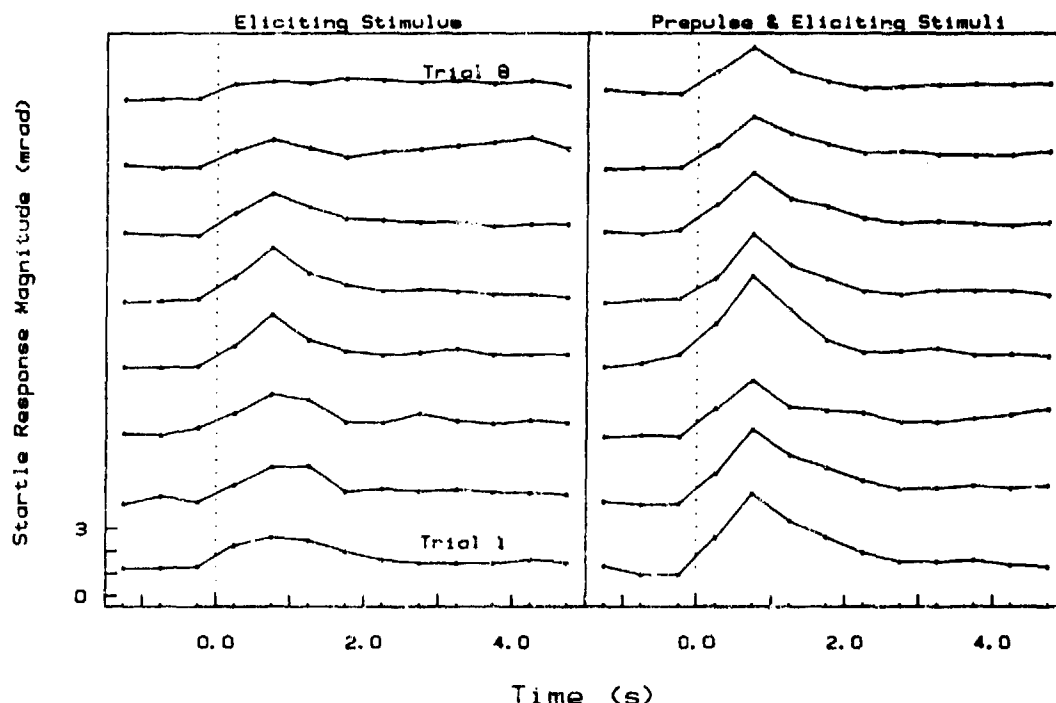


Figure 4. Mean absolute deviations from target before and after noise burst on trials preceded by a cutaneous preliminary stimulus and control trials.

riod of the experiment compared with the second period, $F(1,18) = 11.63$, $p < 0.01$. Both measures declined in strength over trials within periods, $F(3,54) = 7.48$, $p < 0.01$; and the decline in amplitudes was greater over trials in the first period of the experiment compared with the last period, $F(3,54) = 4.96$, $p < 0.01$. There was one difference between the two measures: the trapezius response habituated over trials within each half of the session more rapidly than did the performance errors, for the Trials \times Measures interaction, $F(3,54) = 3.26$, $p < 0.05$. These significant outcomes showed that performance errors and trapezius activity both declined as the experiment progressed and shared a common habituation process. The second significant factor shown in the analysis was the facilitatory effect of the preliminary stimulus on both measures, for the difference between control trials and pre-

liminary stimulus trials, $F(1,18) = 8.03$, $p < 0.05$. This effect did not differ across trials within the experiment, nor did it differ between the two measures, $F_s < 1$.

The analysis of variance revealed that startle reflex expression in the trapezius and disruption of aiming response by the intense noise burst responded similarly to the experimental conditions and thus suggested that the two measures shared some degree of commonality. However, as had been the case for the eye-blink reaction, the similarity of response changes in the two measures should not be understood as a sign of a fundamental connection between them. Correlations were taken of individual differences across subjects in the amplitudes of their elicited trapezius reactions and the size of their performance disruptions, as well as correlations between the measures across individual trials within subjects. Overall these correla-

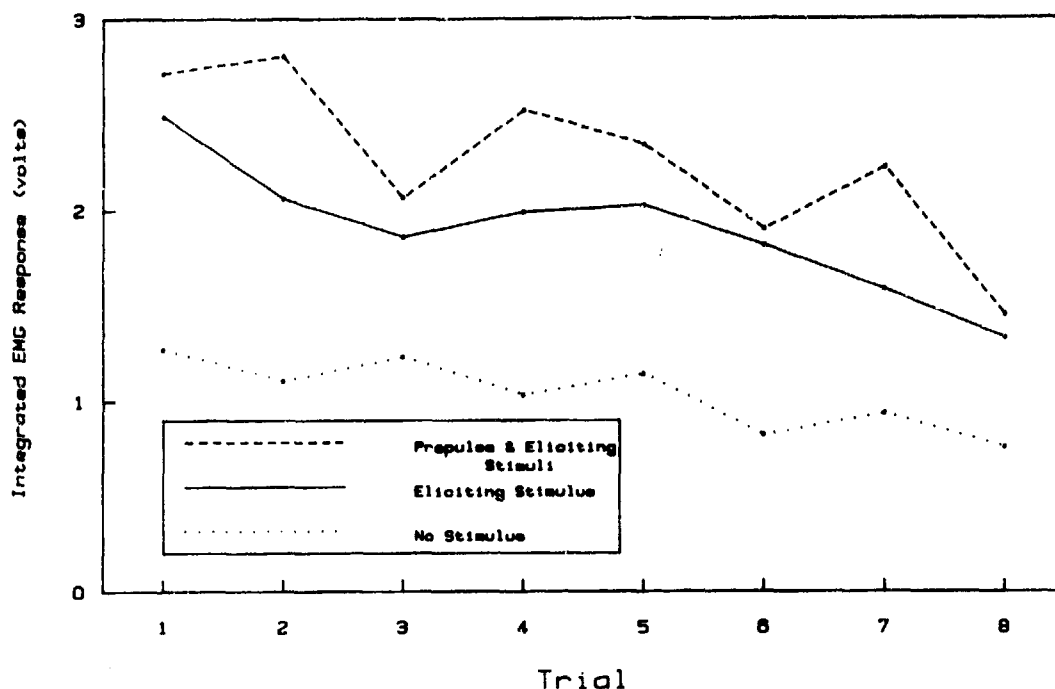


Figure 5. Trapezius muscle response on noise-alone trials and trials with a cutaneous preliminary stimulus.

tions were small and not significant ($r = 0.12, 0.13$). This is the same outcome shown previously for the eye-blink reflex, which also presented essentially zero correlation with the performance disruptions. The failure to find significant correlations was not attributable to any intrinsic unreliability in either measure separately: odd-even reliability estimates computed by means of the Spearman-Brown formula were $r = 0.98$ for performance and $r = 0.97$ for EMG. Thus although trapezius EMG and performance disruptions responded in parallel to the experimental conditions, there is no direct evidence suggesting that disruption in the aiming response occurred as a simple forced consequence of startle reflex expression in the trapezius muscle.

The increase in performance disruption amplitude and EMG activity in the trapezius on the trials with a preliminary cutaneous

stimulus, compared with the trials on which the noise burst was presented by itself, argues that the moderating effect of preliminary stimuli on performance disruption produced by the intense noise burst may be restricted to the use of auditory prestimuli. Previous studies of startle reflex modification using cross-modality stimulus combinations have always found startle reflex inhibition at the inter stimulus intervals used here, whereas in Experiment 4 we found reflex facilitation. It is true that prior studies of startle reflex modification in humans have always measured the eye blink, and thus none has shown that the trapezius muscle is inhibited by preliminary stimuli. However, there is no reason to imagine that trapezius reactions would be different from eye-blink reactions. Reasons for the discrepancy between the facilitatory effect of the cutaneous prestimulus and the inhibitory effect of the

acoustic prestimulus are not now evident. This unexpected finding suggests that those studying startle reflex modification must broaden their scope to consider the nature of the parallel activities in which subjects are engaged at the time reflexes are elicited.

CONCLUSIONS

Intense noise bursts elicit the startle reflex and disrupt the accuracy of an aiming response for several seconds. The present experiments confirmed the earlier finding that startle reflex expression and perceptual motor dysfunction are reduced with repetitive exposure to these stimuli (habituation) and that these effects of the noise recover with the passage of time (spontaneous recovery). The experiments further show that the noise effect is diminished when the subject is forewarned about its time of occurrence and when the noise is briefly preceded by a weak auditory stimulus. The beneficial effects of these manipulations are considerable; each is able to reduce the size of the error produced by the intense noise burst by at least one half.

These data confirm the general expectation that the performance of persons working in an environment that includes occasional intense noise bursts will improve with adaptation to these stimuli. The data further suggest that giving explicit forewarning of these stimuli and presenting weak auditory stimuli immediately prior to their occurrence will provide an additional benefit. If the noise bursts are not predictable, then, following the procedure of Hoffman and Fleshler (1963), the effect might be achieved by an acoustic background with frequent weak sound bursts so that an intense burst is likely to fall into the inhibitory interval set up by the immediately preceding weak stimulus.

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